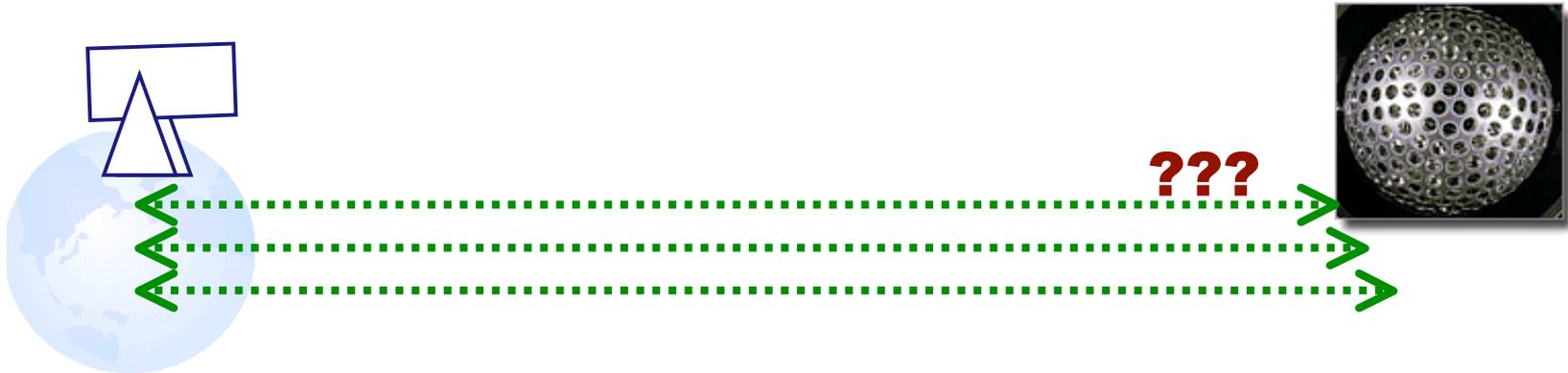


# Centre-of-mass correction issues: Toward mm-ranging accuracy

**Eliminate intensity-dependent biases!**



**Toshimichi OTSUBO**

otsubo@nict.go.jp

National Institute of Information and Communications Technology, Japan  
and

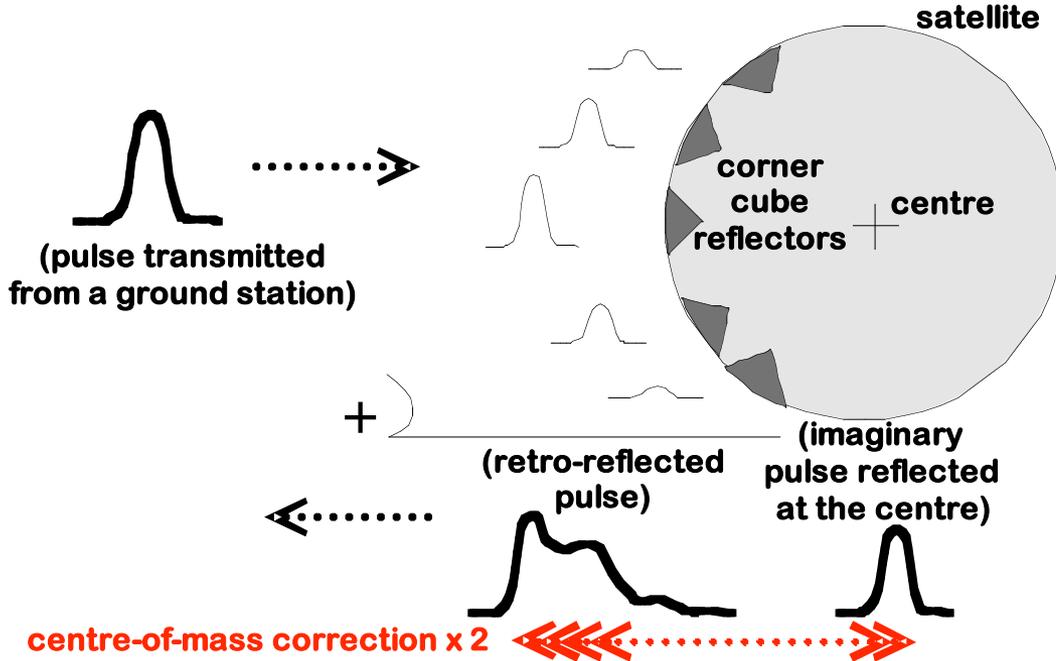
**Graham M APPLEBY**

gapp@nerc.ac.uk

NERC Space Geodesy Facility, United Kingdom

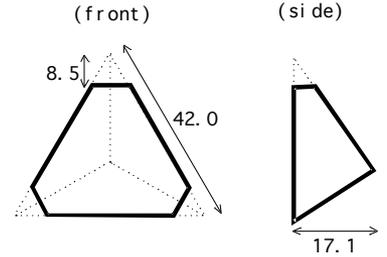
Difficult challenge:  
**We want to achieve**  
**“mm accuracy from cm targets”.**

Very Important:  
**High “accuracy” is NOT equiv to**  
**small single-shot rms.**  
**e.g. Hx single-shot rms = 15 mm.**



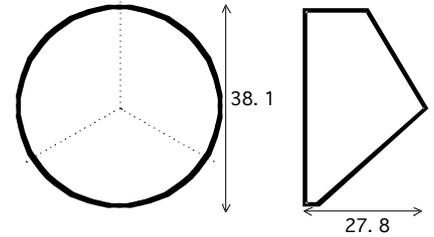
**AJSA**

fused silica  
 $n=1.46$   
 no coating on back faces



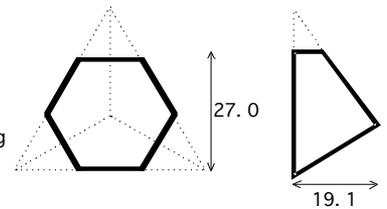
**LAGEOS**

fused silica  
 $n=1.46$   
 no coating on back faces



**ETALON**

fused silica  
 $n=1.46$   
 aluminium coating on back faces



# Response function

Average retroreflection return pulse shape assuming a 0 ps incident pulse width.

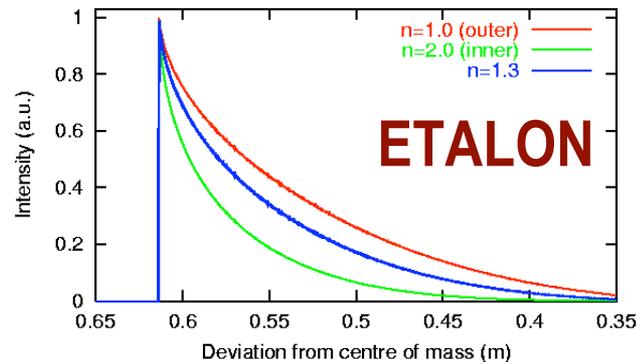
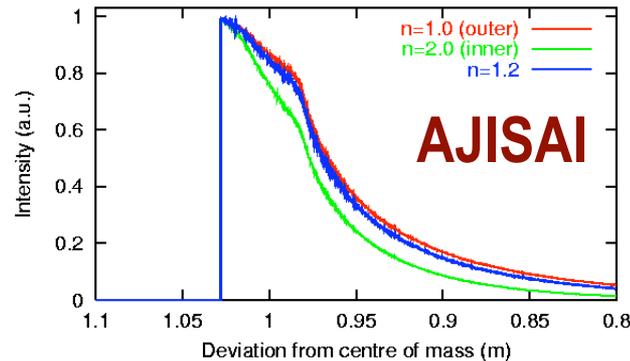
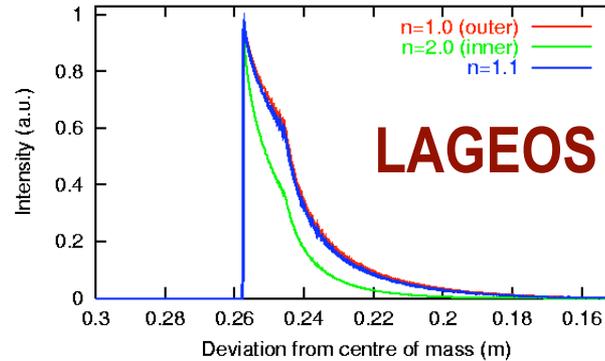
## Centre-of-mass correction

for high energy system

... approx. at leading edge

for single photon system

... approx. at centroid

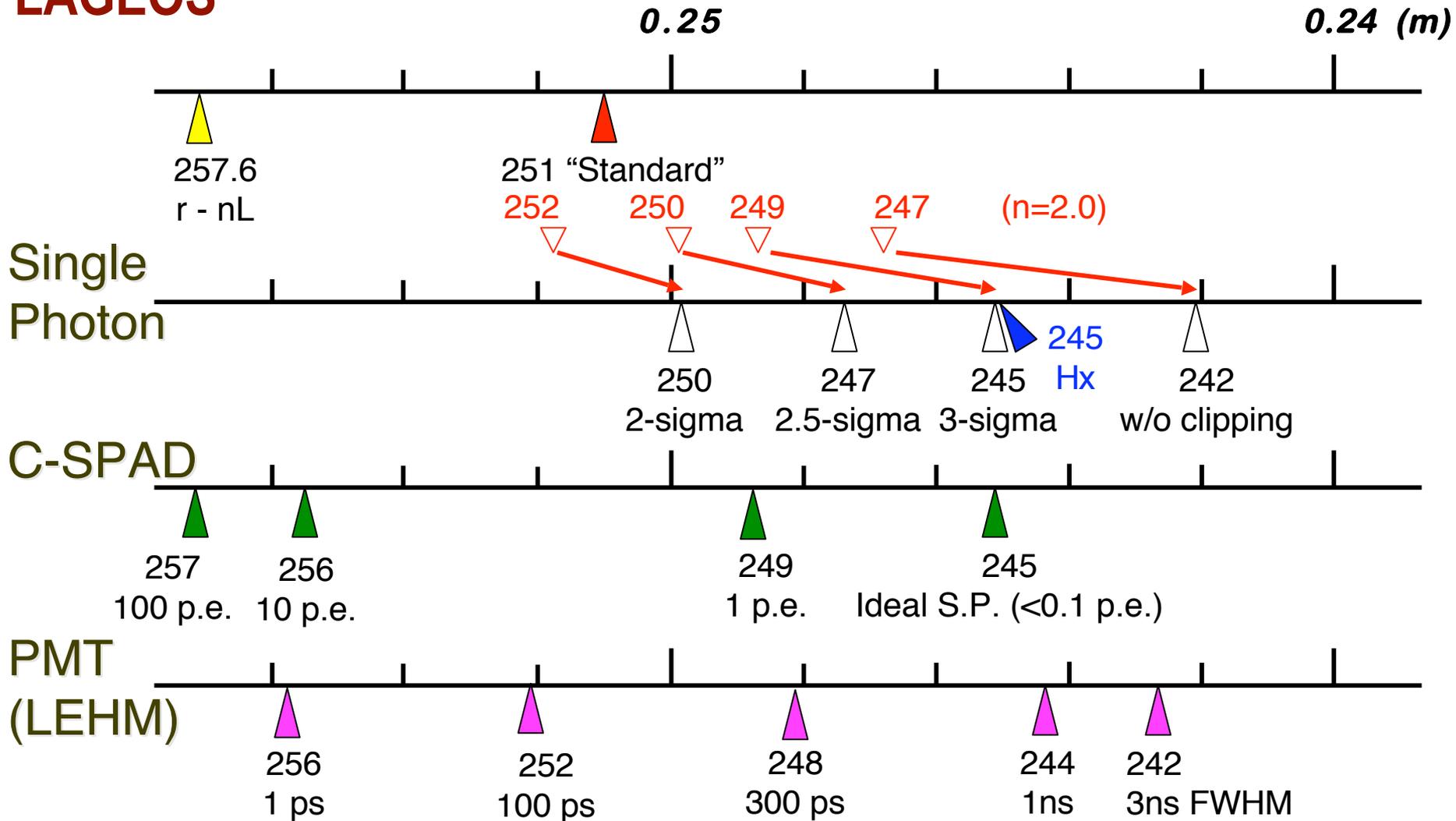


Red: n=1.0  
Green: n=2.0  
Blue: best-fit

# System-type-dependent centre-of-mass correction

From Otsubo and Appleby, JGR, 2003.

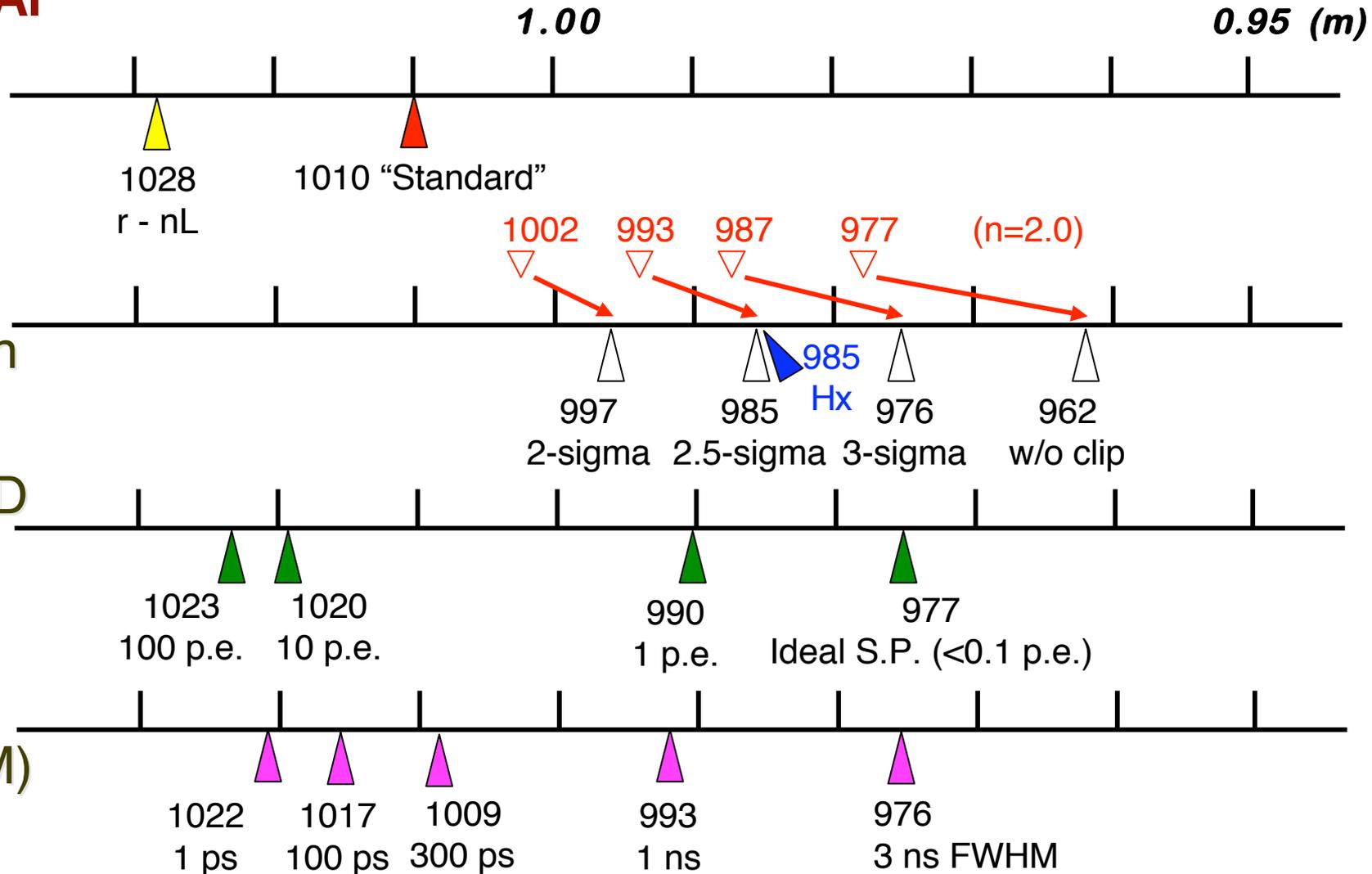
## LAGEOS



# System-type-dependent centre-of-mass correction

From Otsubo and Appleby, JGR, 2003.

## AJISAI



# System-type-dependent centre-of-mass correction

From Otsubo and Appleby, JGR, 2003.

## ETALON

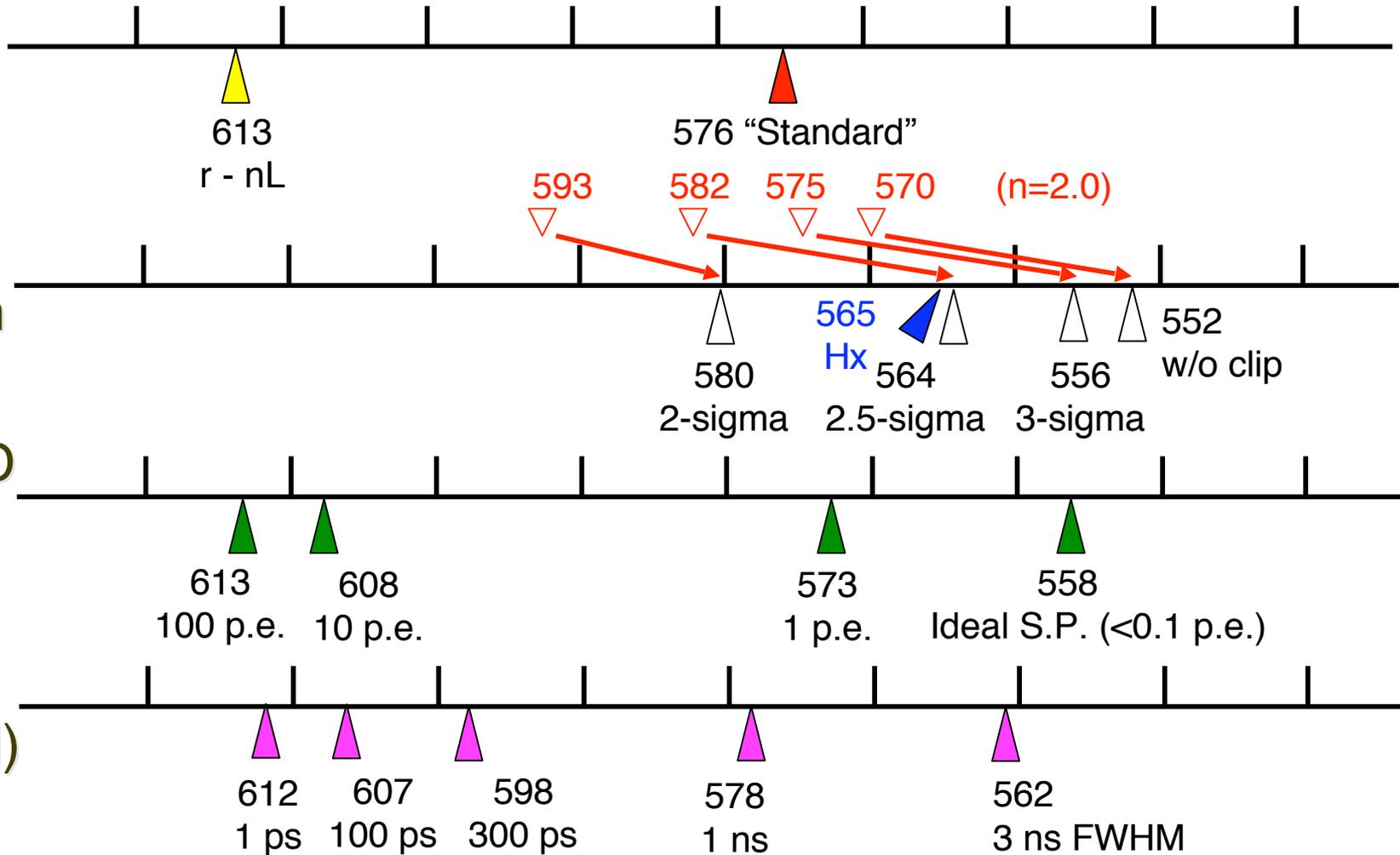
0.60

0.55 (m)

## Single Photon

## C-SPAD

## PMT (LEHM)



---

## The most guilty “error” ... intensity-dependent range bias

### **C-SPAD users:**

**“C-” does NOT mean “compensated” for actual targets!  
Control the return energy (preferably at single-photon).**

### **MCP-PMT users:**

**Probably not so serious as C-SPAD,  
but not sure at 1-mm accurate level.**

**Likely to be elevation-angle-dependent error**

**We should test at each station! cf: following 2 speakers**

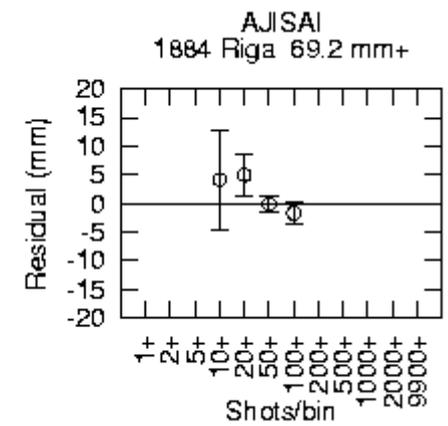
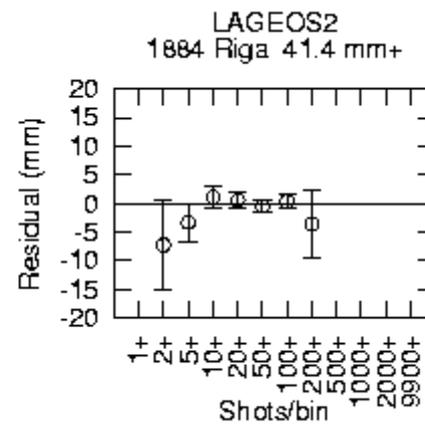
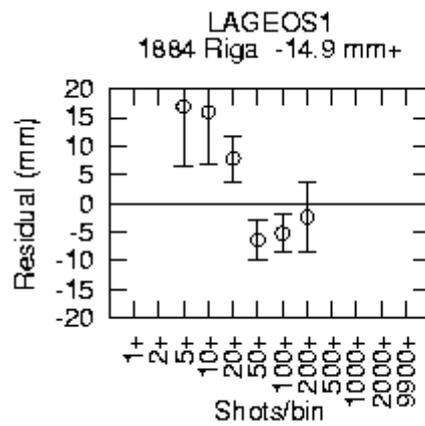
*Wilkinson and Appleby (C-SPAD at Herstmonceux)*

*Carman, Noyes and Otsubo (MCP+CFD at Yarragadee)*

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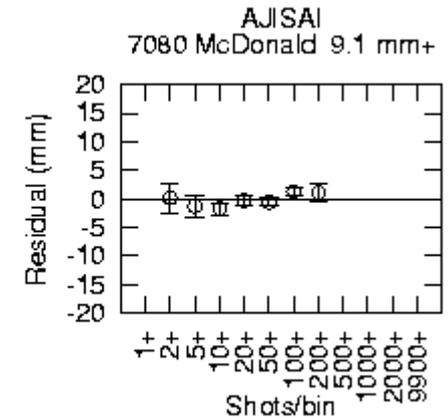
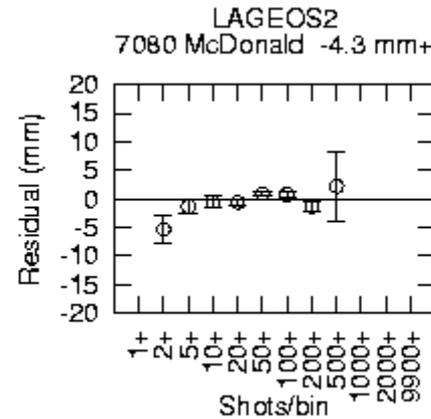
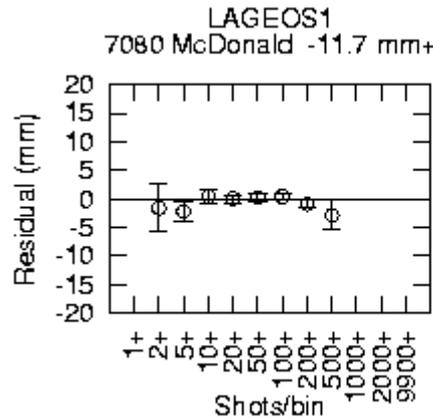
# Residual analysis

Apr 03  
To  
Feb 04



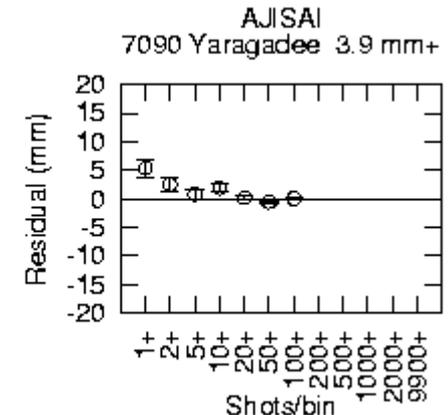
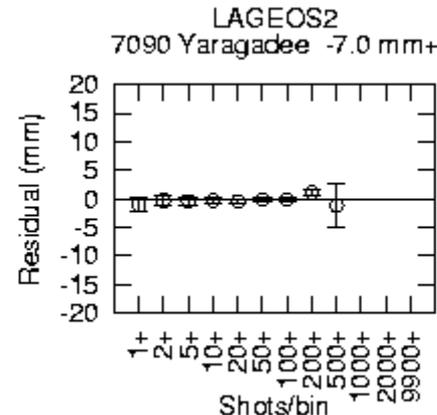
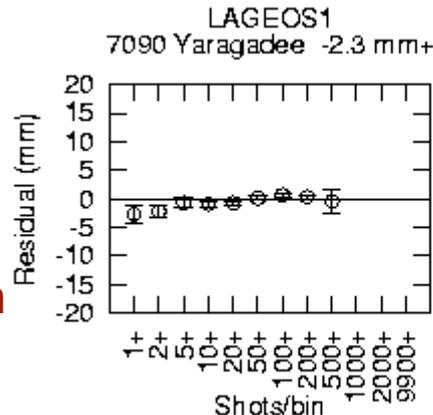
## Orbit determination

5-day arc for LAG  
2-day arc for AJI  
Station coordinates  
Range bias



## Intensity dependence

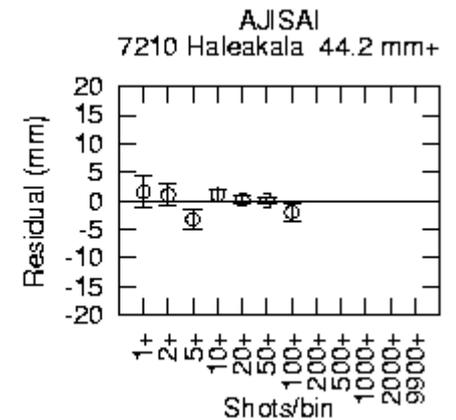
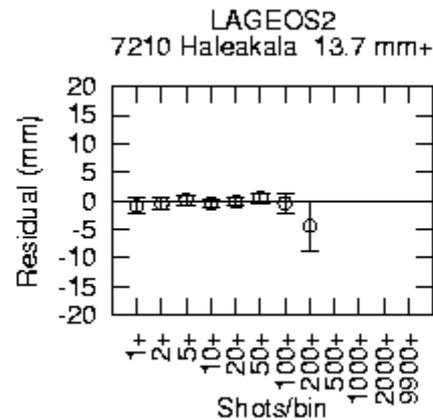
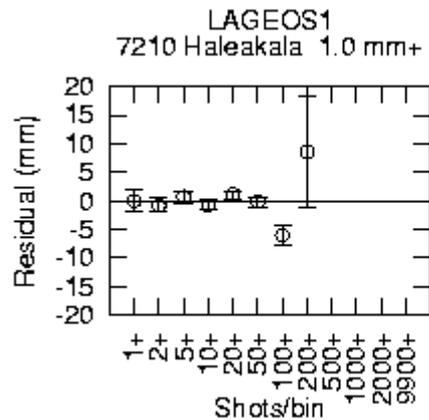
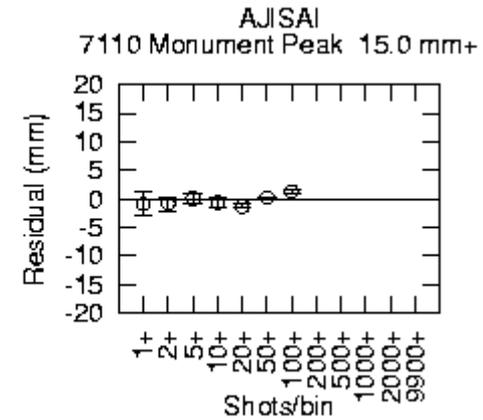
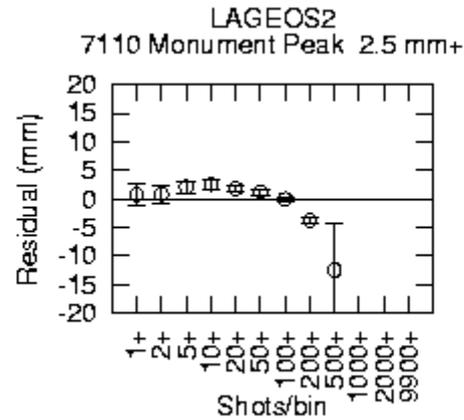
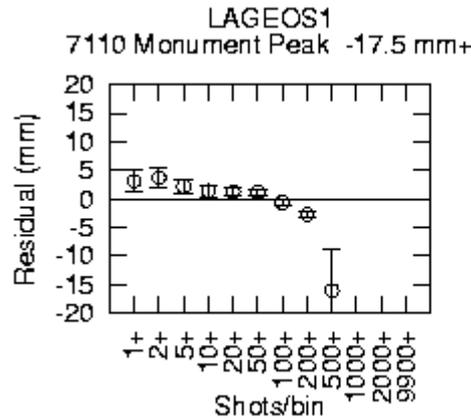
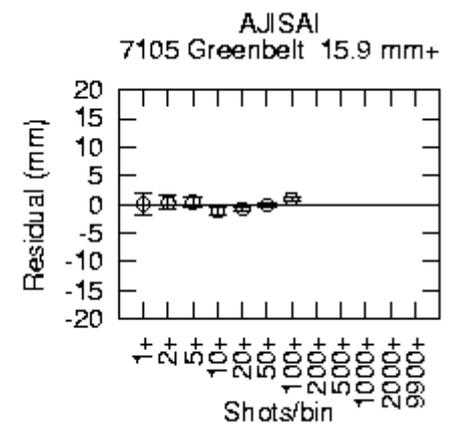
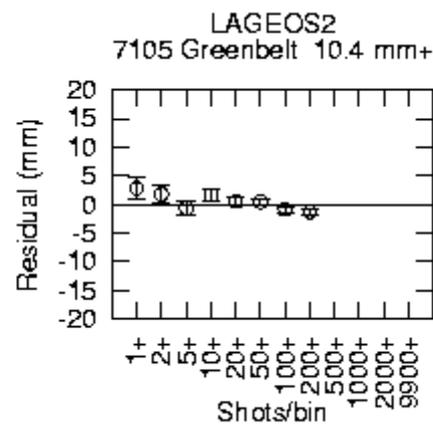
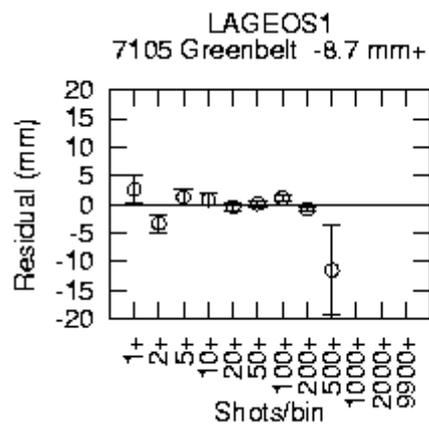
Post-fit residuals  
sorted by #ss/bin



Ignore the points with  
large error bars

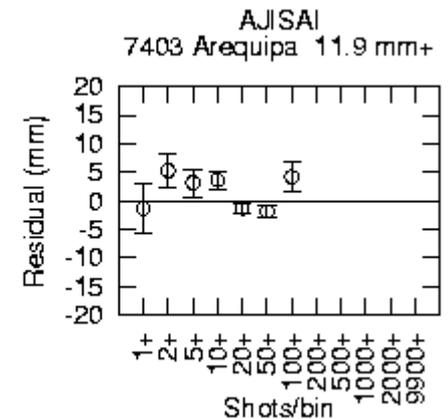
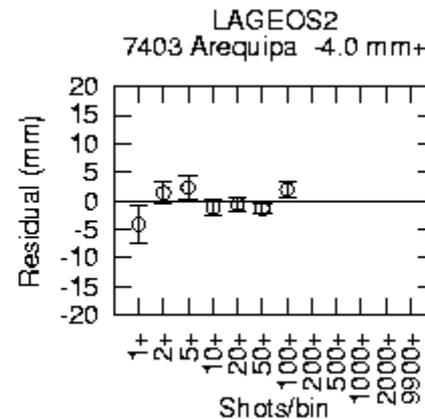
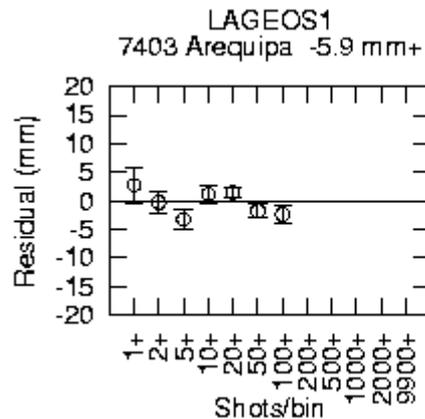
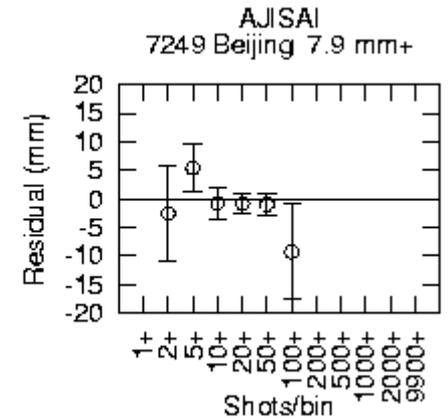
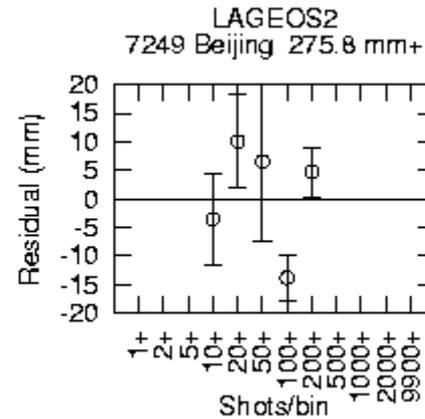
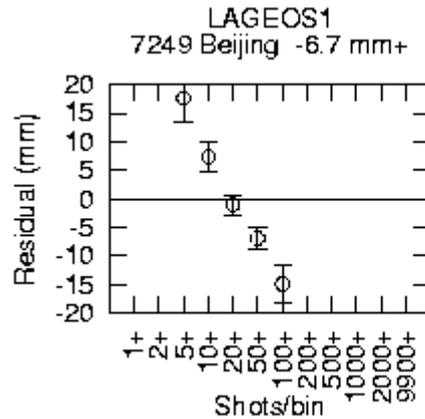
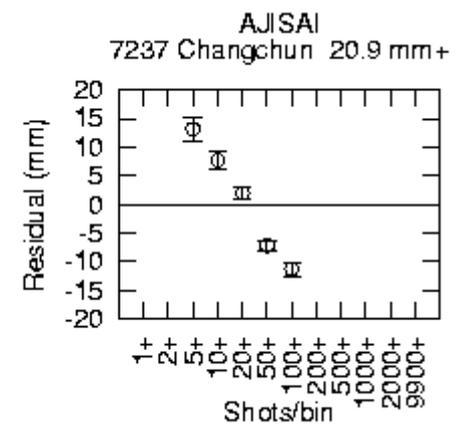
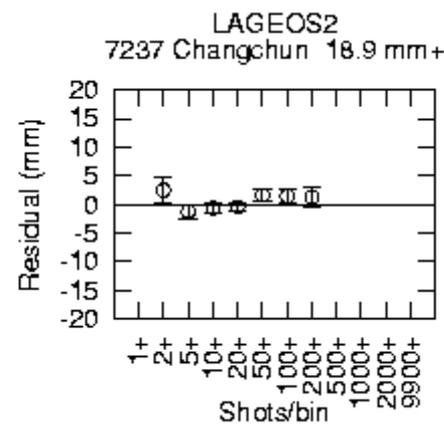
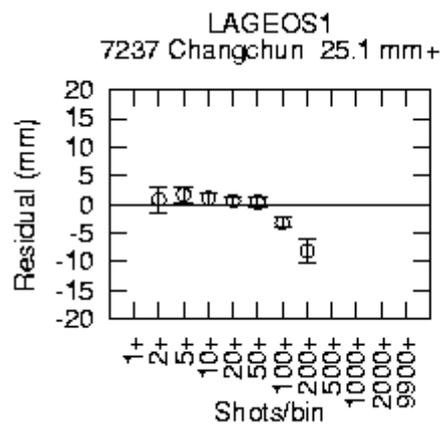
# Residual analysis

Apr 03  
To  
Feb 04



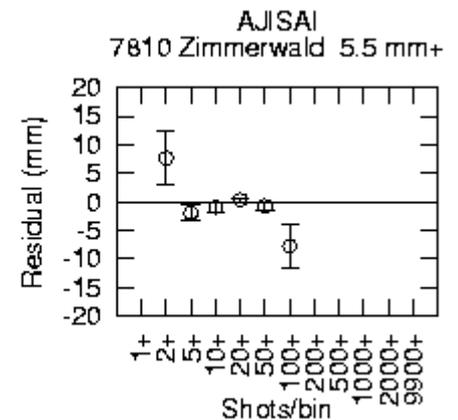
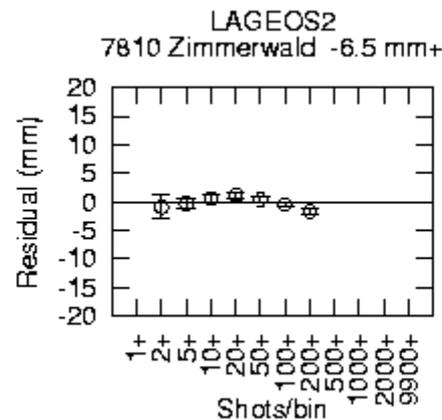
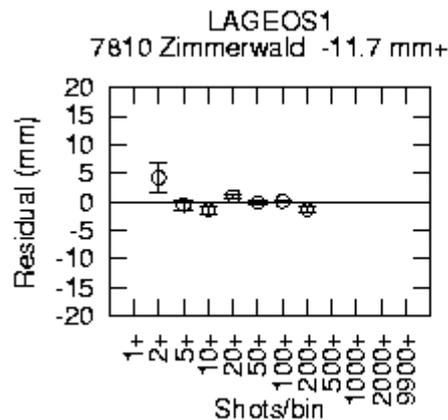
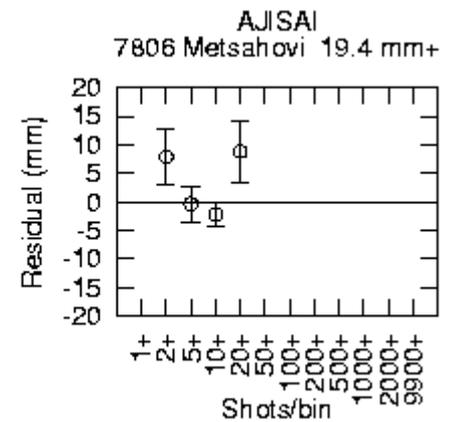
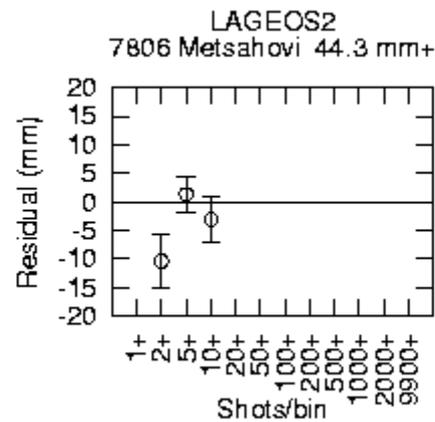
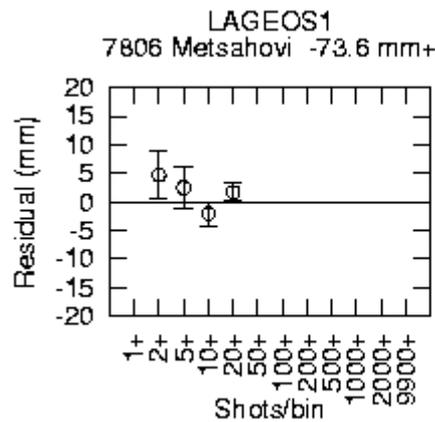
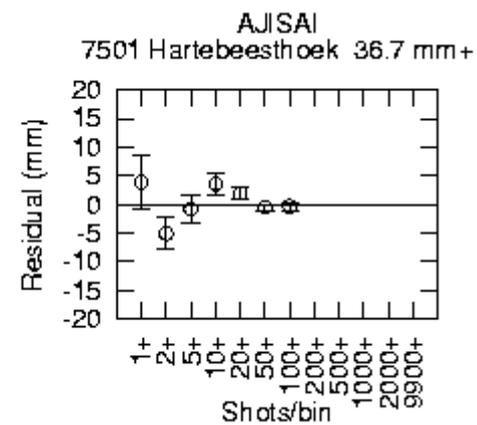
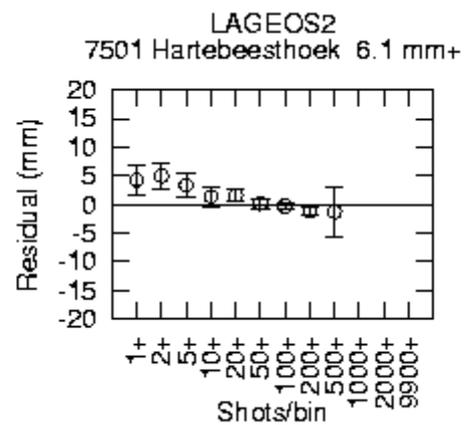
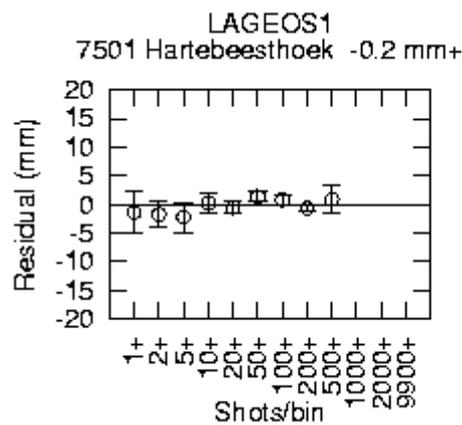
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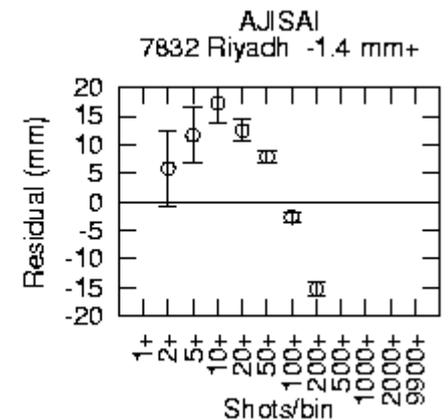
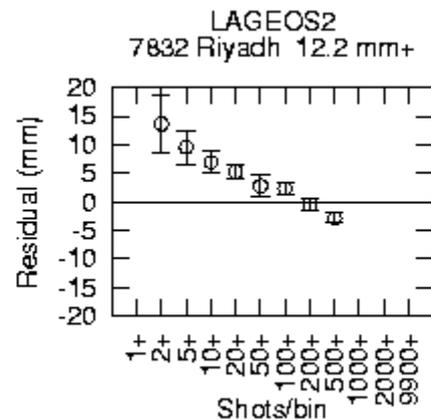
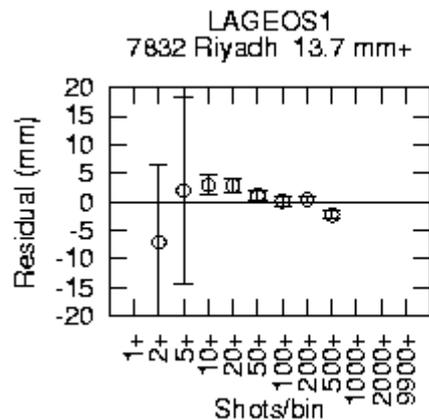
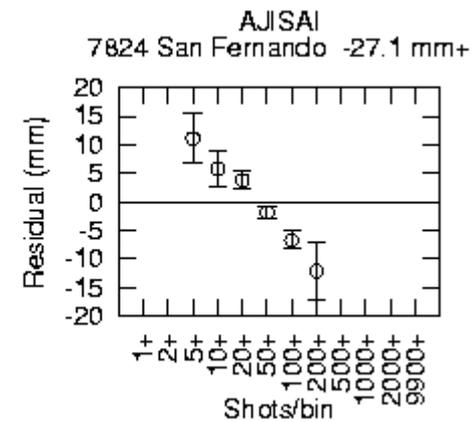
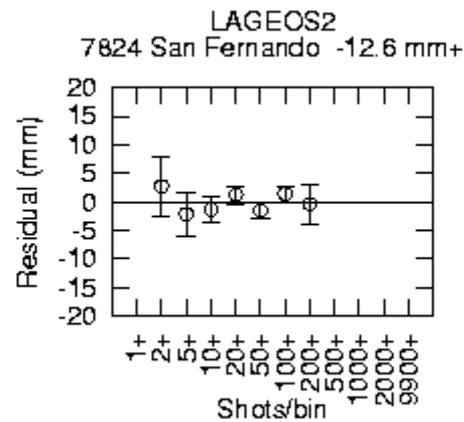
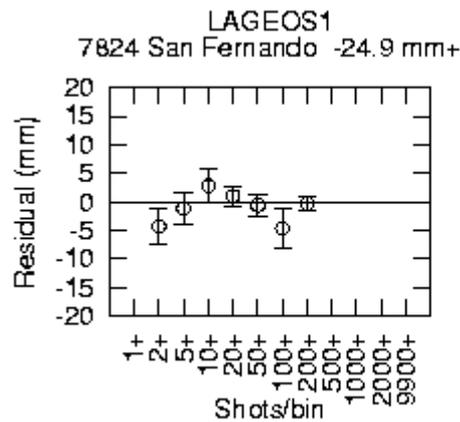
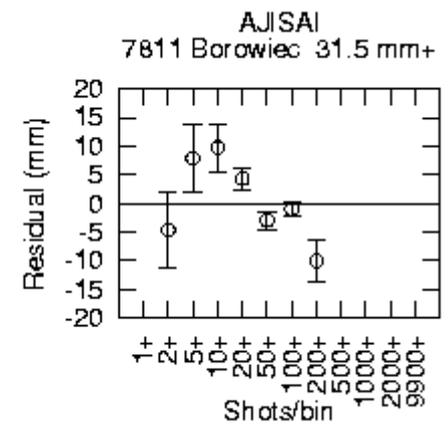
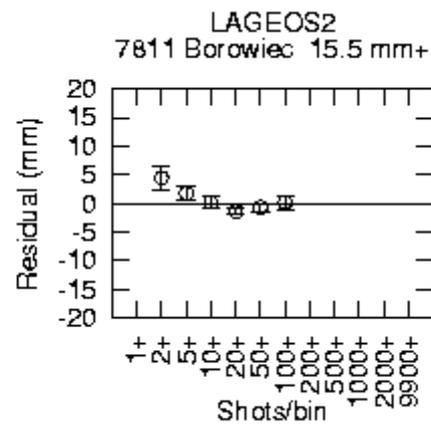
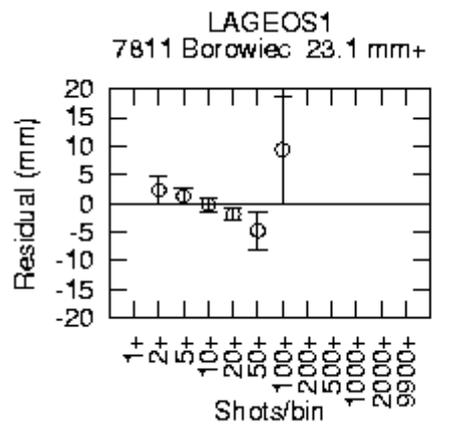
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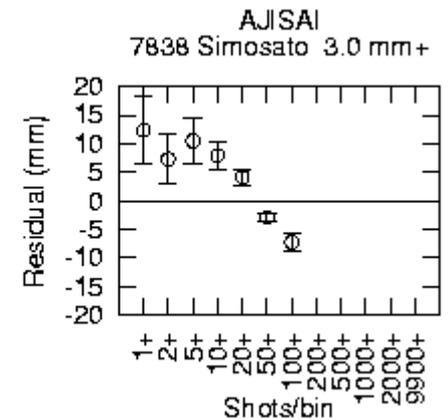
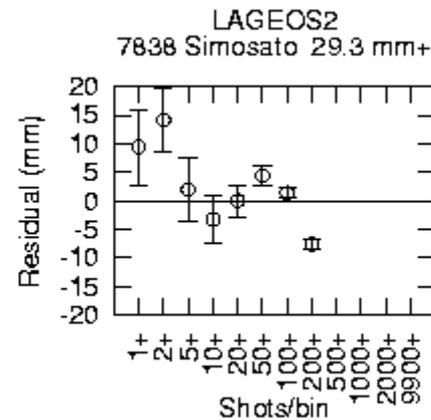
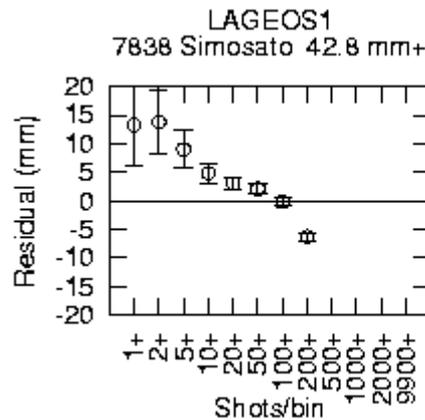
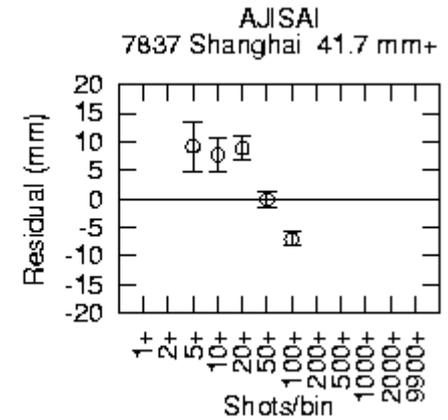
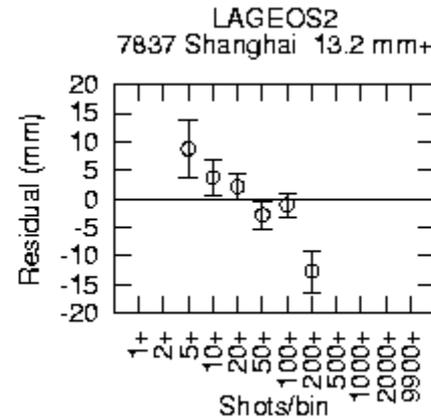
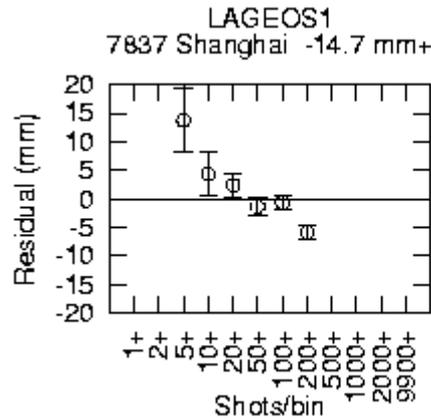
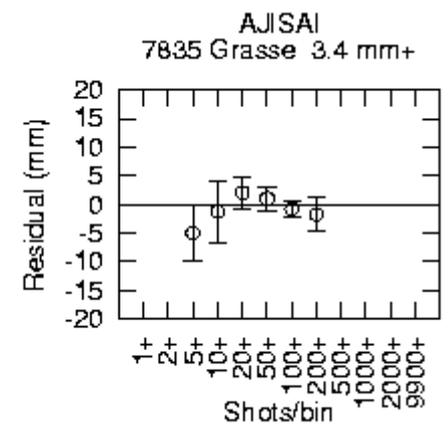
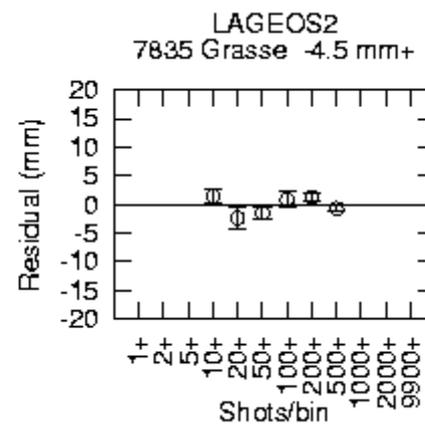
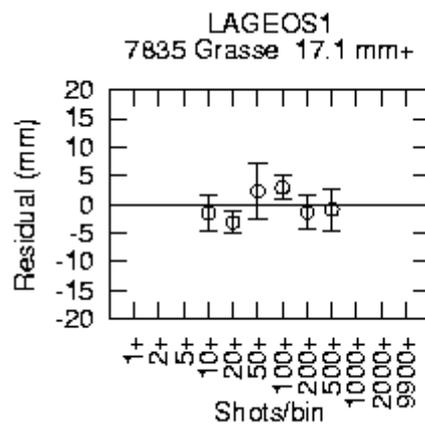
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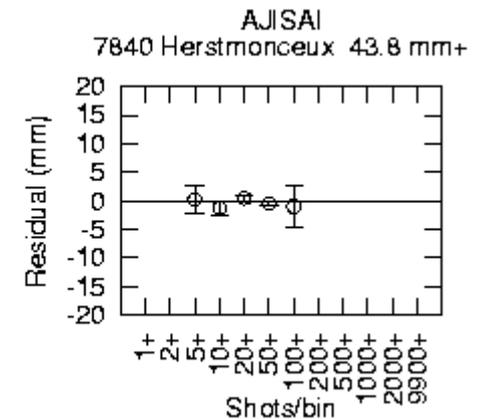
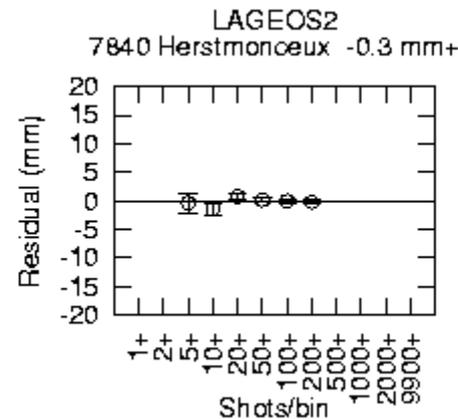
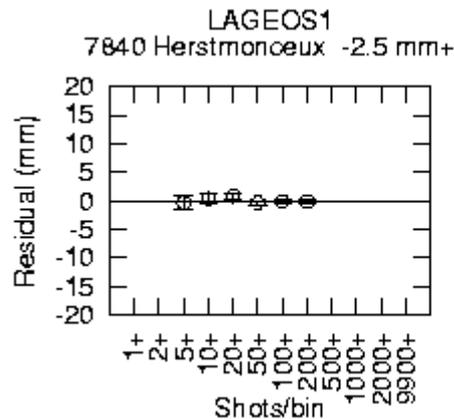
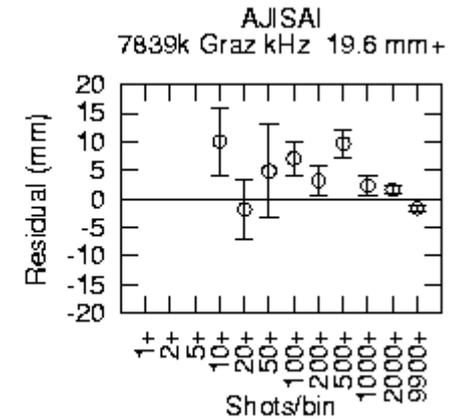
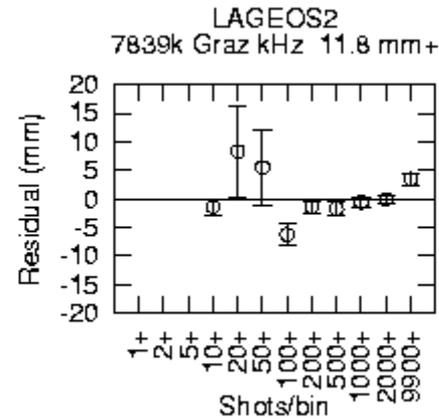
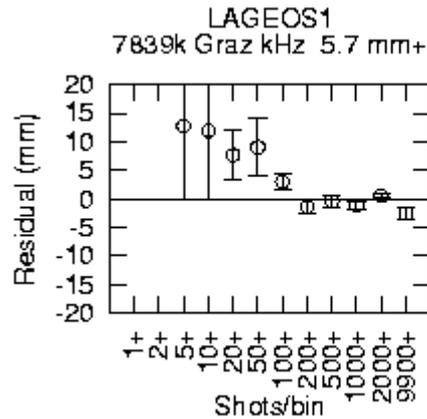
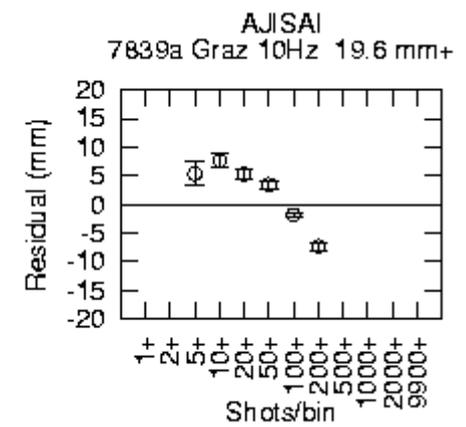
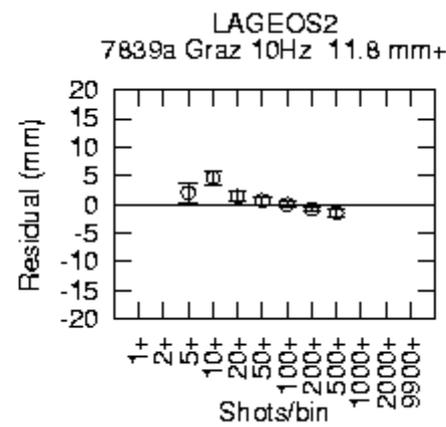
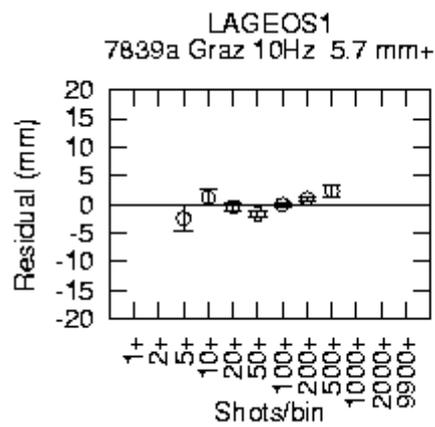
# Residual analysis

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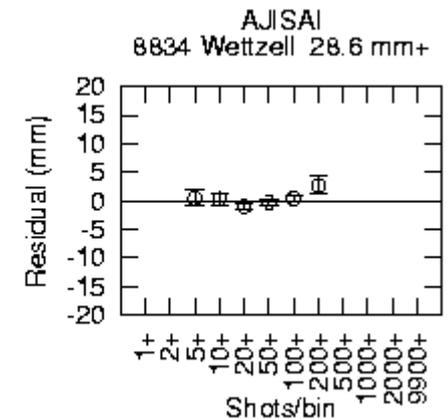
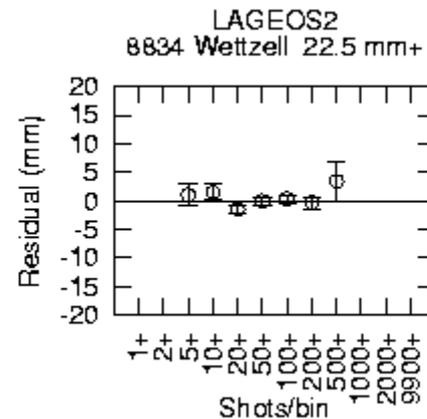
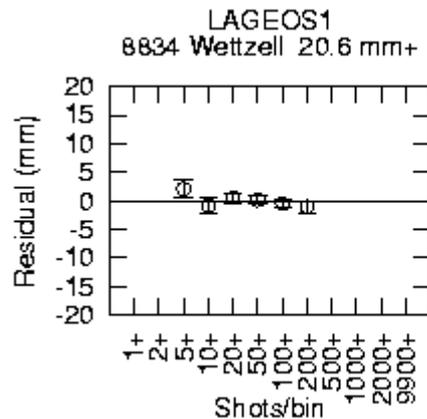
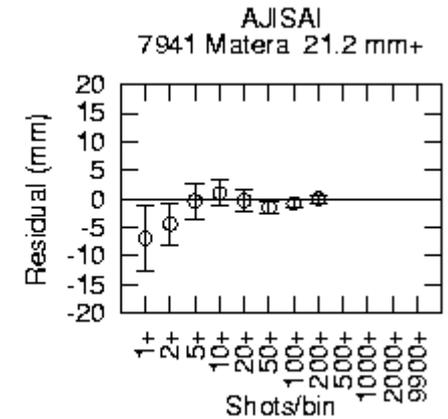
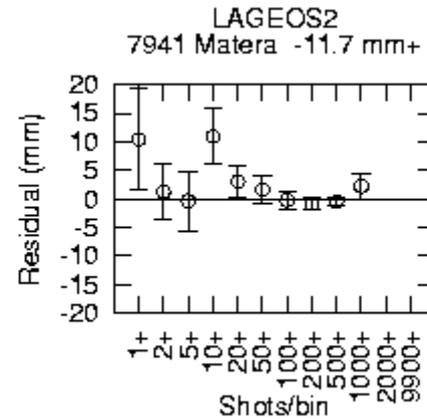
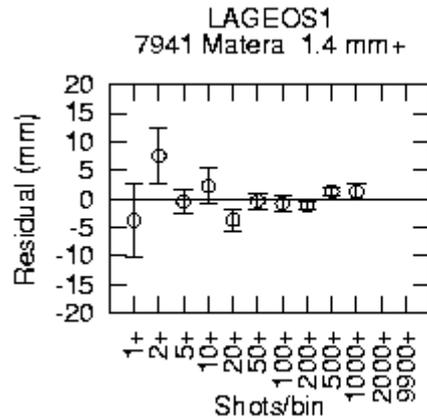
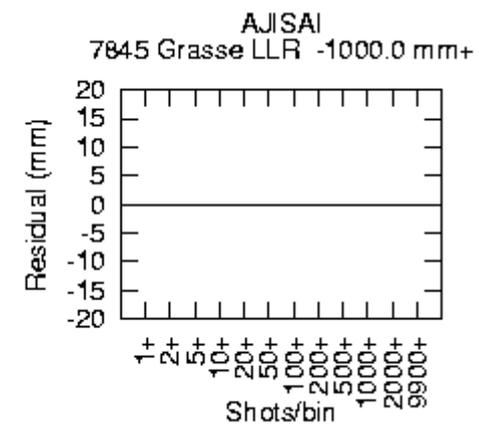
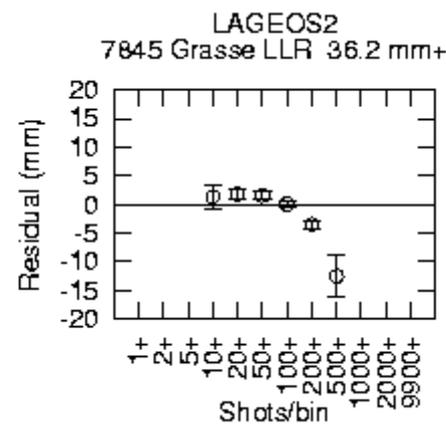
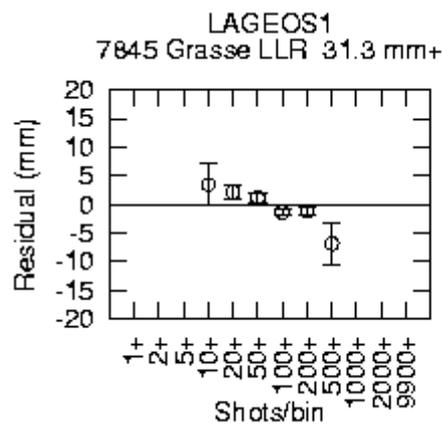
# Residual analysis

Apr 03  
To  
Feb 04



# Residual analysis

Apr 03  
To  
Feb 04



## Residual analysis “bias vs intensity 2003-04”: summary

The intensity dependence is underestimated in this analysis.

**Intensity-dependent → Elevation-angle-dependent  
→ absorbed in parameter estimation**

**Very Important:**  
DO NOT be relieved  
even if your station  
looked ok.

### Overall verdicts

**Single photon systems (Hx, and Zimm also?) behave very good.**

**MCP systems also good, but a few mm trend seen.**

**C-SPAD systems have “the stronger, the shorter” trend.**

**... typically p-p 5 cm for AJISAI, p-p < 1 cm for LAGEOS**

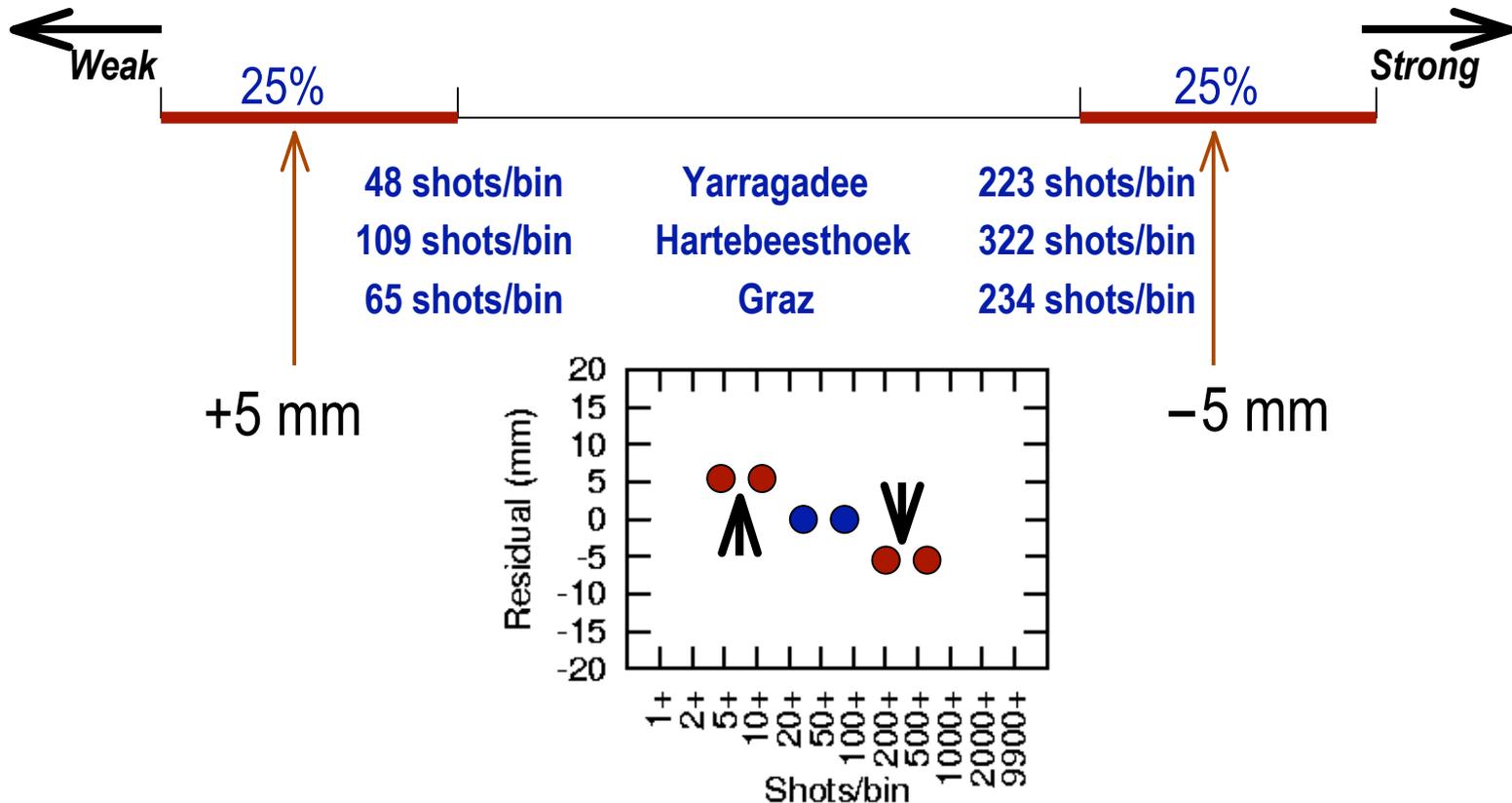
**Graz kHz ... difficult to tell ← too many “9999” data.**

# How guilty of corrupting geodetic result is intensity-dependent range bias?

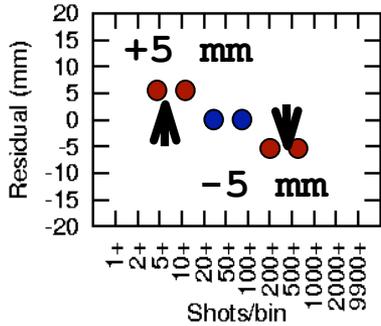
Adding artificial bias to raw LAG1 NP data (50 days: 21 Apr to 9 Jun 03)

Station: Yarragadee (7090), Hartebeesthoek (7501) and Graz (7839)

Intensity = number of single-shot returns per NP bin

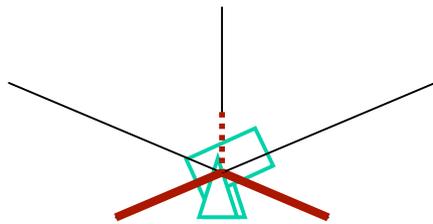


# How guilty of corrupting geodetic result is intensity-dependent range bias?



**Orbit determination with Pos+RB estimation, with and w/o introducing artificial bias**

**Difference  
Artificial - Original**



Yarragadee

Height +7.4 mm  
Range bias +4.2 mm  
(orig +5.1 mm)

Hartebeesthoek

Height +8.4 mm  
Range bias +4.8 mm  
(orig +8.9 mm)

Graz

Height +6.0 mm  
Range bias +4.9 mm  
(orig +0.1 mm)

## Conclusions: mm accuracy from cm targets?

**LAGEOS is a “large” satellite now!**

**Eliminate the intensity-dependent bias!**

C-SPAD does not fully compensate for satellite returns.

MCP systems are more robust, and single-photon systems are the most.

Intensity robustness should be TESTED at EVERY station (cf. following 2 speakers)

Strong-Weak test for LAGEOS, AJISAI and any LEO with small CCR array.

Please report at the future workshops!

This bias contaminates the geodetic solutions.

Do not pleased with small single-shot rms.

Do not pleased with high single-shot return rates.